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Impact of Plastic Waste on The Volumetric Characteristics and Resilient Modulus of Asphalt Concrete

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Abstract

Recently, the use of plastic in many products has led to a huge amount of plastic waste, which is typically difficult to treat and expensive to recycle. This problem has been considered by many researchers and environmental organizations as requiring serious considerations about recycling and reusing plastic waste in different fields, such as asphalt mixtures. In this paper, aggregate passing a 4.75-mm sieve was replaced by 5, 7, 9, and 11% of plastic bottles used for drinking purposes. The dry method was adopted in this work, and the changes in the mixture's volumetric properties were investigated using the Marshall method. A repeated indirect tensile load test was also conducted to determine the mixture's resilient modulus. Marshall's stability, air voids, unit weight, flow, and voids in mineral aggregates were examined. The results were compared and analyzed with the base sample. It was observed that adding plastic decreased aggregate consumption and reduced the optimum asphalt content (OAC). Additionally, the volumetric properties of the mixture improved and its service life was extended after adding plastic. It was also observed that the value of the resilient modulus (RM) increased when the percentage of added plastic increased as well. Reuse of plastic in asphalt mixtures achieves the concept of an environmentally friendly solution in the transportation area because it reduces the amount of asphalt and aggregates and reduces the costs of recycling plastic. Moreover, the optimal plastic content in this paper was achieved at 11%.

Keywords: Plastic Waste; Dry Process; Resilient Modulus; Asphalt Concrete.

1. Introduction

The use of plastic materials has become prevalent when introducing asphalt mixtures. There is a great deal of research in this field examining the effect of its applications on the development of flexible pavements on roads. In addition, the increase in traffic loads on roads necessitates serious consideration of reusing materials that improve the asphalt's characteristics, extend its service life, and thereby reduce periodic maintenance costs. Using plastic materials in such projects reduces the cost of recycling them and their environmental impact. On the other hand, industrial technology and developed applications have led to the progression and widespread use of plastic in areas such as eating utensils, drinking bottles, and food containers. The use of plastics or polymers in asphalt mixtures has become a common subject of extensive research to achieve sustainability and reduce environmental pollution. Therefore, integrated tests and investigations should be conducted on any added materials to asphalt mixtures to ensure their economic viability, performance, and extent of development.

The use of plastic materials has been extensively discovered in past research. The dry method was conducted by adding four types of plastics as a partial replacement in the asphalt-concrete mixture. Plastic contents were added at 4, 6, and 8% by the bitumen weight. Many tests, including volumetric properties, gyratory compactor, Marshall, and

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indirect tensile tests, were utilized. The researchers concluded that adding plastic does not reduce the elasticity property of asphalt mixtures and increase the stiffness of the surface layer to the point of permanent deformation [1]. Researchers from Indonesia applied polymer materials to paving mixtures to improve their strength and durability. Certain percentages of Low-Density Polyethylene (LDPE), Polyethylene terephthalate (PET) and Polypropylene (PP). The tests of indirect tensile strength (ITS), unconfined compressive strength (UCS), permeability, and Cantabro were conducted to investigate disintegration resistance in the modified mixtures. The outcomes of this research showed that the mixtures containing PP had the best results in the aforementioned tests, and the modified PP mixture can be used as an asphalt concrete wearing course with impervious characteristics [2].

Moreover, the evaluation of using a high-density polyethylene plastic additive on the asphalt concrete cycle was tested. About 42 samples were prepared using different proportions of high-density polyethylene (HDPE) plastic seeds (from 0 to 7% with an increment of 1% by weight of asphalt) and met the OAC at 5.5%. The wet method of mixing was applied to determine the properties of Marshall parameters such as stability, flow, voids in mineral aggregates, voids filled by asphalt, and the Marshall quotient. The findings presented showed that the influence of HDPE plastic seed content improved Marshall properties and achieved the required specifications [3]. Testing of added PE to the paving mixtures was conducted to evaluate elastic viscosity, workability, strength, moisture sensitivity, and resistance to permanent deformation. A comparative laboratory study was implemented using densely graded mixtures and different amounts of PE (i.e., 0, 0.25, and 1.5% by mixture weight). The results showed no significant differences between the modified mixture and the base mixture based on workability and moisture sensitivity. However, the resistance to permanent deformation and strength give better results compared to base mixture results [4].

A study of the influence of temperature on the value of RM in many asphaltic samples was carried out in Iraq. The asphalt mixtures were prepared to contain two kinds of asphalt with various percentages and fillers such as cement and limestone. The results showed that the RM value decreases as temperature increases, and the RM of an asphalt mixture containing cement filler is greater than that of a mixture containing limestone [5]. In addition, the maximum total nominal volume was found to be affected by the RM and incubation period [6]. Additionally, previous studies utilized environmentally hazardous iron filings as plastic waste in asphalt samples. The material was added in different proportions to study the mechanical properties and RM of asphalt. It was found that 5% yields the best results by improving asphalt concrete sample stability and flow values, as well as showing the highest RM value [7, 8]. An investigation of developing asphalt properties by incorporating plastic waste for road pavement construction was conducted. The dry method was adopted to prepare asphalt concrete samples containing 5, 10, and 15% plastic particles. The comparison results with the base asphalt samples indicate that the penetration and ductility resistance of modified samples increased from 0 to 12% and show that the optimal finding was set at 8.4% plastic content [9].

Furthermore, it was concluded that the use of plastic in asphalt might increase the softening point, service life, and thereby resistance to rutting [10]. Improvement of moisture resistance and better performance of asphalt concrete mixtures were obtained from OAC at 5.8% and adding different plastic particle contents of 25, 50, and 100% by weight of remained aggregates on sieve No. 40 openings. The Marshall tests were carried out to examine asphalt concrete durability characteristics in addition to other tests such as indirect tensile strength (ITS) and the indirect tensile stiffness modulus (ITSM) [11]. Also, the resilient modulus and stability values of mixtures including recycled rubber powder and crumb rubber from vehicle tiers were added as 0.5, 1, 1.5, 2, and 4% to aggregates. The universal material testing equipment was used at various temperatures. The results verified an increase and improvement in the Marshall indicators and RM of modified samples relative to base samples [12]. Adding percentages of 10, 15, and 20% LDPE plastic was examined in preparing recycled asphalt pavement (RAP) with a treatment of 0, 2, and 4% new asphalt. The results showed a significant increase in stability despite the increase in cavity properties of the modified samples [13].

On the other hand, an empirical work from the UAE used the wet method to apply plastic waste to bitumen to investigate the rutting behavior of flexible pavement under heavy traffic loads and hot weather conditions. The plastics are used as small pieces, passing through a sieve of 150-μm and remaining on a sieve of 75-μm. Different amounts of added plastic were prepared at 0.2, 0.5, 1.0, and 5.0% of bitumen weight. The rotational viscosity as an indicator of the stiffness of asphalt binder and binder dynamic shear modulus tests were conducted under various temperatures. The results showed that adding plastic particles to asphalt binder may increase its viscosity and stiffness properties for all tested samples of asphalt binders. Therefore, adding plastic to the bituminous binder may reduce rutting behavior at service temperatures [14]. Additionally, two types of polyethylene particles plastics: polyethylene (PE) granules and residual polyethylene (by a product of the former, currently incinerated after production) were blended with a conventional asphalt binder to examine their chemotherapy, thermal, and mechanical properties. Differential scanning calorimetry (DSC), infrared spectroscopy (FTIR), environmental scanning spectroscopy (ESEM), and thermogravimetric analysis (TGA) were carried out to evaluate the different types of PE, the degree of chemical modification, the thermal characteristics of blended asphalt, and the quality of the blend. A dynamic shear scale (DSR) was used to study the rheological performance of the PE-blended particle binders. The results presented showed that the binder resistance against high-temperature triggers was significantly improved after adding PE particles in comparison with that of commercial polymer-modified binders [15]. Moreover, asphalt containing PP and PE prepared by the orthogonal test was used to examine the mechanisms of dispersion and modification of plastic particles in modified asphalt. The outcomes showed that the modified samples showed better performance at high temperatures in comparison to the conventional asphalt sample [16]. Furthermore, the wet method has been used to assess the effects of adding different amounts of plastic cup. The proportions 0.5, 1, 2, 3, 4, and 4.5% were used in a previous study as a percent of asphalt weight [17]. The results presented showed that asphalt including 2% polymer concrete in the base showed better consistency compared to asphalt with more than 2% PC. This is due to the fact that increasing PC content results in harder bitumen because of the expansion of the polymer chain.

At last, the use of PET was studied as additive in various amounts (from 0 to 10% with an increment of 2% by weight of asphalt) in stone mastic asphalt (SMA) mixtures was studied, and the best results of Marshall stability and flow were shown at 4% PET content and 5.5% bitumen content [18]. Added plastic bottles waste to the asphalt mixture via the wet method by 15, 20, 25, and 30% of OAC. The researchers concluded that Marshall stability increased significantly at 15% of added plastic particles compared to other contents and the conventional mixture [19].

1.1. Resilient Modulus (RM)

The resilient modulus (RM) of flexible pavement is also known as the modulus of elasticity. It can be defined as the basic material character in a multilayer system for linear and non-linear elastic behavior under repeated loads. It is one of the most essential properties of road costs that can be investigated and evaluated when adding polymers to asphalt material. Frequent experiments and studies have been conducted for 30 years and over to calculate and examine the RM of asphalt. However, this has proved challenging to determine because it depends on natural stress and must also be accurately calculated in a laboratory under controlled conditions. Furthermore, its value may be affected by temperatures, weather conditions, and the quality of the asphalt mixture composition.

The earliest formula was established by Heukelom & Foster (1960) [20], then developed by Lister and Powell in 1987. Both models were used to determine RM based on the California Bearing Ratio (CBR) value of grained soils with a certain range (i.e., 5–10%); however, the effect of stress was not considered. The relationships can be written as follows:

- Heukelom and Foster model [20]:

$$RM = 1500\, CBR \tag{1}$$

- Lister and Powell model [21]:

$$RM = 2555\, CBR^{0.64} \tag{2}$$

Next, the above relationships were developed including different types of stress and atmospheric pressure in order to obtain an approximate estimation of RM value. The predicted models can be listed as follows:

- Uzan et al. model [22]:

$$RM = k_1 \sigma_{atm} \left[\frac{\theta}{\sigma_{atm}}\right]^{k_2} \left[\frac{\sigma_d}{\sigma_{atm}}\right]^{k_3} \tag{3}$$

- AASHTO model [23]:

$$RM = k_1 \theta^{k_2} \tag{4}$$

- Pezo and Hudson model [24]:

$$RM = k_1 \sigma_d^{k_2} \sigma_3^{k_3} \tag{5}$$

- NCHRP model [25]:

$$RM = k_1\, \sigma_{atm} \left[\frac{\theta}{\sigma_{atm}}\right]^{k_2} \left[\frac{\tau_{oct}}{\sigma_{atm}} + 1\right]^{k_3} \tag{6}$$

where θ is the bulk stress in psi, τ_{oct} is the octahedral shear stress in psi, σ_d, σ_3 and σ_{atm} are deviator stress, confining and atmospheric pressures in kPa, respectively, k_1, k_2 and k_3 are regression coefficients in kPa.

The RM controls fatigue cracks caused by tensile stresses at the bottom layer of asphalt concrete and permanent deformation through the pavement. The RM under uniaxial dynamic loading represents a quantitative association between the greatest stress and the greatest unit deformation. Generally, the asphalt paving materials are inelastic; therefore, frequent loads will cause a permanent effect. When the resistance of the material becomes greater than layer strength and loads from traffic, a significant portion of the deformed asphalt might be restored and qualified as an elastic material.

1.2. Volumetric Properties

Volumetric properties play an important role in improving the quality and service life of asphalt mixtures. The first volumetric characteristic of asphalt mixtures is the air voids (AV) ratio between aggregate particles, which has a significant effect on mixture durability. There is an inverse relationship between air voids and asphalt content [26]. Moreover, a higher content of AV results in an oxidation effect on the asphalt mixture and a decrease in mixture density and quality. Conversely, the lack of air spaces can lead to excess asphalt being squeezed out of the mixture onto its surface. Prediction models were established by researchers [27, 28] and show evidence that measured RM is related inversely with the content of AV as well as other relative factors such as temperature, viscosity, asphalt content, and a specific aggregate composition on certain sieves:

- Leahy model [27]:

$$\log RM = \frac{\log S}{-8.652 + 4.27 \log T + 1.01 \log S - 0.233 \log V + 0.992 \log AC_{eff} + 0.476 \log AV} \tag{7}$$

- Fonseca and Witczak model [28]:

$$RM = function\ (V, f, AC_{eff}, AV, R_{3/4}, R_{3/8}, R_4, P_{200}) \tag{8}$$

where AC_{eff} is effective asphalt content by volume in percent, AV is air voids ratio, f is the frequency of load in Hz, P_{200} is the percentage of passed aggregate from sieve No.200, $R_{3/8}$, $R_{3/4}$, R_4 are the percentages of retained aggregate on sieves ⅜, ¾ and 4, respectively, S is applied stress in psi, T is temperature in ˚F, V is asphalt viscosity in 10^6 poise at 20 ˚C.

In general, voids in mineral aggregates (VMA) can be expressed as the air spaces between aggregates in addition to voids filled with asphalt. There must be a minimum ratio of VMA to ensure that aggregates cover and absorb asphalt as much as possible. In addition, a decrease in the void content in mineral aggregates may reduce the durability of the mixture and have an effect on the performance measures of the Marshall mix design method in terms of stability and flow.

2. Methods and Materials

2.1. Dry and Wet Processes

There are two approaches to adding plastics to asphalt mixtures that can be utilized: wet and dry processing. In the wet method, small pieces of plastic are added to hot bitumen to create a homogenous mixture, which is then added to the aggregate composition. Otherwise, plastic particles are added to aggregates at high temperatures (nearly to the softening point of plastic) to cover the aggregates, which is commonly known as the dry method. The advantages of the technique of wrapping aggregates with plastic are to prevent moisture damage to asphalt mixtures and achieve a rise of service life of asphalt concrete mixtures. The dry method yields greater Marshall's stability and stripping values than the wet method, as mentioned by Khan et al. [9]. In the current study, the dry method was adapted. Figure 1 depicts the steps of the study methodology. The materials used and experimental works are described in detail as presented in the next sections.

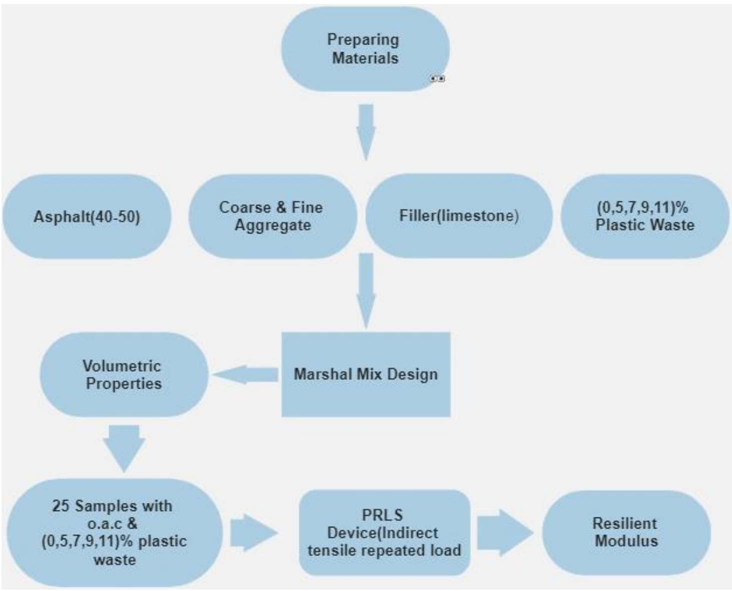

Figure 1. Research methodology flowchart

2.2. Materials

2.2.1. Asphalt Binder

A class of grade 40/50 asphalt binder was used in this work that produced by Al-Nasiriyah refinery. Special results were obtained from physical examinations and can be shown in Table1. The tests were conducted following the ASTM procedures and the outcomes were met the Iraqi specification of SORB/R9 [29].

Table 1. Physical properties of asphalt cement

Property	Test conditions	ASTM designation	Test results	SORB/R9 [29]
Penetration	25ºC, 100 gr, 5 sec	D5-06	43	40-50
Softening Point	-	D36-95	49	-
Ductility	25ºc, 5 cm/min	D113-99	146	>100
Specific Gravity	25˚C	D70	1.03	
Flash Point	Cleave open land cup	D92-05/ After Thin Film Oven Test D1754-97	301	>232
Retained Penetration of Residue (%)	25ºC, 100 gr, 5 sec	D5-06	79	>55
Ductility of Residue	25ºC, 5 cm/min	D113-99	88	>25

2.2.2. Aggregate Composition

Fine and coarse aggregates as well as the limestone dust were obtained from Assur Company's quarries. Several tests were conducted according to ASTM. The results can be presented in Tables 2 to 4.

Table 2. Properties of coarse aggregates

Property	ASTM, 2013 Designation No.	Test results
The bulk specific gravity of coarse aggregate	C127-88	2.62
The apparent specific gravity of coarse aggregate	C127-88	2.687
Absorption in percent of coarse aggregate	C127-88	1 %
Percentage of fractured particles in coarse aggregate	D5821-13	94 %
Resistance to abrasion (Los Angeles)	C131/C131M-2014	23%

Table 3. Properties of fine aggregates

Property	ASTM, 2013 Designation No.	Test results
The bulk specific gravity of fine aggregate	C128-01	2.629
The apparent specific gravity of fine aggregate	C128-01	2.694
Absorption in percent of fine aggregate	C128-01	1.1 %

Table 4. Properties of mineral filler (Limestone dust)

Property	Test results
Percentage passing sieve No. 200	95 %
Specific surface area (m^2/kg)	389
Specific gravity	2.85

2.2.3. Plastic Waste

In this work, samples were prepared using the dry method after cutting the used plastic drink bottles into small pieces. The particles were passed through sieve opening of 4.75 mm and retained on a 2.36 mm sieve. Plastic particles of used bottles were applied in different contents to replace fine aggregates of the same size. The proportions used asphalt concrete mixture were as follows: 0 (for base sample), 5, 7, 9 and 11%.

2.2.4. Selection of Combined Gradation

Aggregates combination was prepared for sieve analysis following the Iraqi specifications [29] of wearing course as outlined in Table 5. In addition, Figure 2 shows the gradation of the aggregate that was implemented.

Table 5. Allowable limits of aggregate gradation according to SORB/R9 [29]

Sieve size (mm)	Passing % by weight of total aggregate and filler
	Wearing course Type Ⅲ-B
37.5	100
25.0	100
19.0	100
12.5	100
9.5	90-100
4.75	55-85
2.36	32-67
0.300	7-23
0.075	4-10

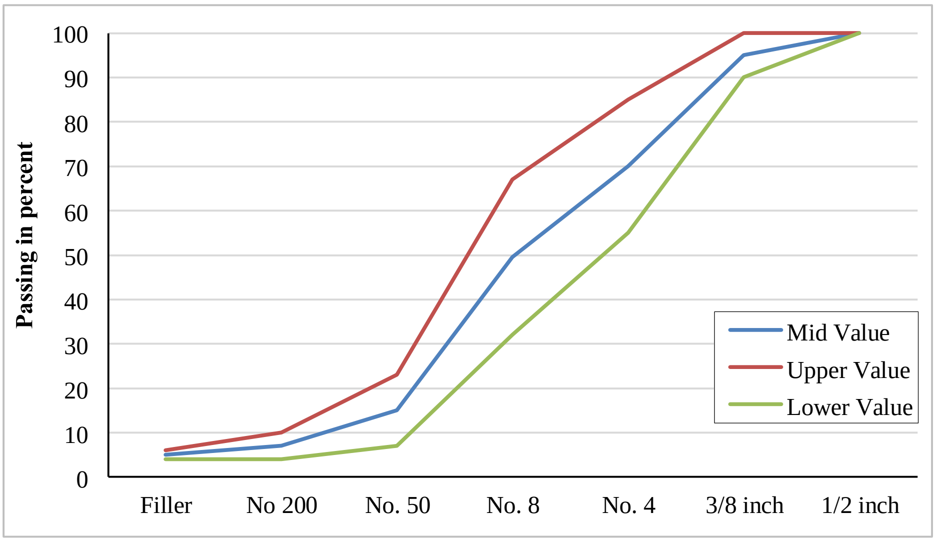

Figure 2. Aggregate gradation

2.3. Marshall Mix Design Method

As described in the previous sections, the required materials were used in the preparation of asphalt concrete mixture based on ASTM D6926. After drying the fine and coarse aggregates at 110 °C, the Marshall design molds were prepared. Fine and coarse aggregates were heated to 160 °C, then melted plastic was added and thoroughly mixed with the aggregates to achieve homogeneity. The limestone filler and bitumen were added to the aggregates and thoroughly mixed with a spoon so that the aggregate was well coated in bitumen. The mixtures received 4, 4.5, 5, 5.5, and 6% bitumen contents along with 0, 5, 7, 9, and 11% plastic particles. To this end, 75 samples were prepared (i.e. five samples for each asphalt content to determine the optimal asphalt content, then 3 samples for each added plastic content). The prepared mixture was placed in the molds, then compacted with 75 blows using a falling hammer from 457.2 mm perpendicular distance on the top and bottom mold bases after removing the collar and plate. The molds were left for 24 hours for cooling. After removing the samples from the molds, the Marshall design tests were conducted to determine the optimal asphalt value for each sample. The optimal asphalt content was determined, as well as the stability, flow, voids in the mineral aggregate (VMA), and air voids ratio. Then, samples were prepared using the same proportions of plastic with the obtained OAC. The samples were subjected to an indirect repeated axial load test using the pneumatic repeated load device (PRLS) to compute the resilient modulus (RM).

2.4. Pneumatic Repeated Load System (PRLS)

The optimal asphalt content for each percentage of added plastic particles was determined by preparing samples and subjecting them to indirect tensile repeated load using a pneumatic repeated load system (PRLS). The diagonal sample was subjected to indirect tension at a constant frequency of 60 cycles per minute, with a load duration of 0.1 second and rest period of 0.9 second between each cycle, a stress level of 0.138 MPa, a temperature of 25 °C and an indirect tensile load of 1200 repetitions. Figure 3 depicts the pneumatic repeated load system device.

Figure 3. PRLS device and indirect tensile test

3. Results and Discussion

3.1. Volumetric Properties

A study of the volumetric properties of the asphalt concrete mixture reveals the required amounts of aggregate and bitumen to create a homogeneous mixture that provides workability and resistant to the moisture conditions. The summary of the results is shown in Table 6.

Table 6. Marshal test results and optimum asphalt content (OAC)

Test Type	0% plastic particles	5% plastic particles	7% plastic particles	9% plastic particles	11% plastic particles	SORB/R9 Specification [29]	Remarks
AV, %	4.1	4.1	4	3.8	3.7	3-5%	Accepted
Unit Weight, gm/cm^3	2.41	2.39	2.38	2.36	2.36		
VMA, %	15.6	15.6	15.8	16	16.1	Min 14%	Accepted
VFA, %	75	78	78	79	78		
Marshall Flow, mm	3.2	3.2	3	2.9	2.7	2-4 mm	Accepted
Marshall Stability, kN	10.6	10.8	11.3	11.6	12.1	Min 8 kN	Accepted
OAC, %	5.2	5.1	4.8	4.7	4.5	4-6%	Accepted

According to Iraqi Standard Specification for Roads and Bridges [29], the accepted AV should be within the range of (3 – 5%) for wearing pavement layer type Ⅲ-B. As illustrated in Figures 4 to 8, the air voids content, unit weight and flow decreased as the proportion of added plastic increased. However, the values of Marshall's stability and VMA increased. Reducing the percentage of air spaces decreases the mixture's permeability, thereby increasing its moisture resistance. Furthermore, the exudation rate increases due to increased pressure between aggregates and the absence of air spaces between them. Increasing the value of VMA increases the adhesion between aggregates and the adhesive materials then consequently increases the asphalt's durability. The increase in the Marshall stability value of the mixture is due to adding of plastic particles to the mixture which cause a decrease in the viscosity of the mixture. Similar results were reported by Sarsam & Al Tuwayyij [8].

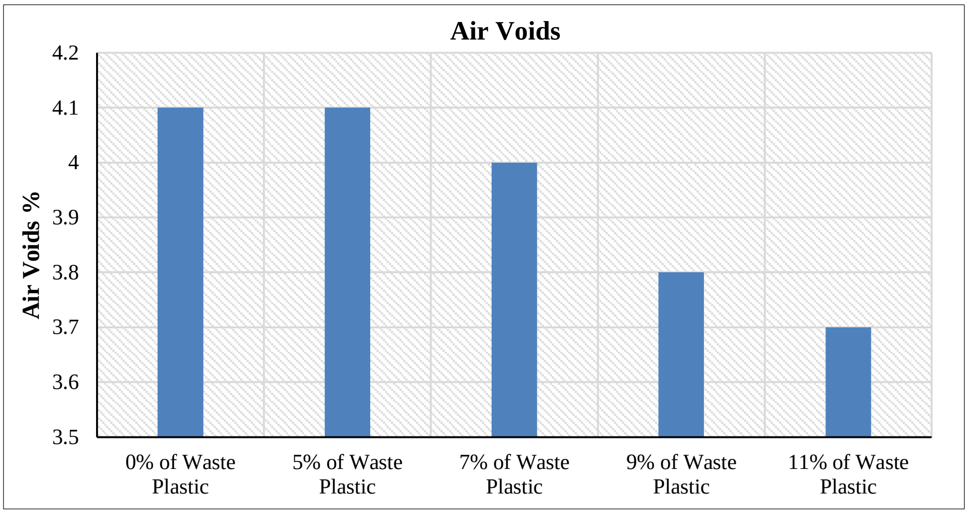

Figure 4. Air voids versus percentage of added plastic particles

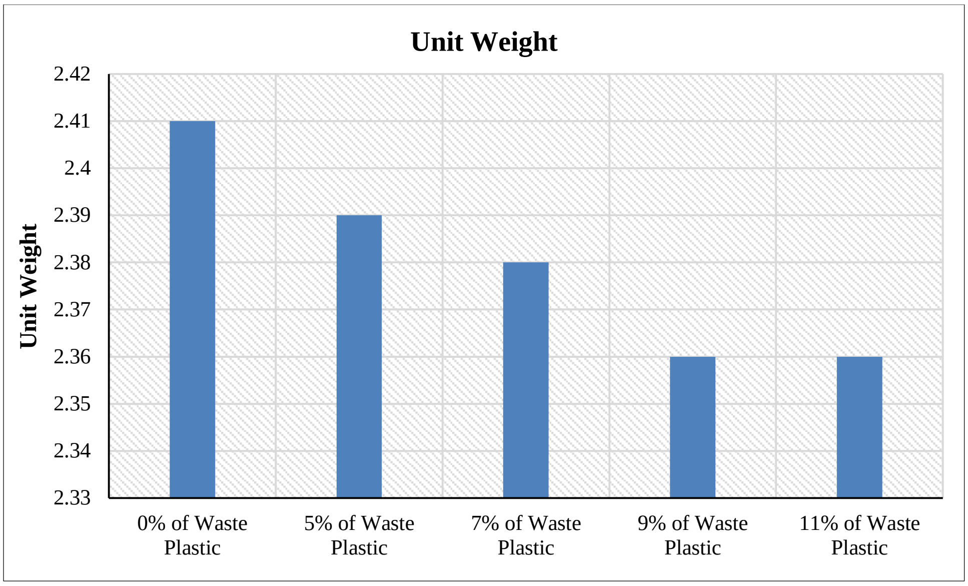

Figure 5. Unit weight versus percentage of added plastic particles

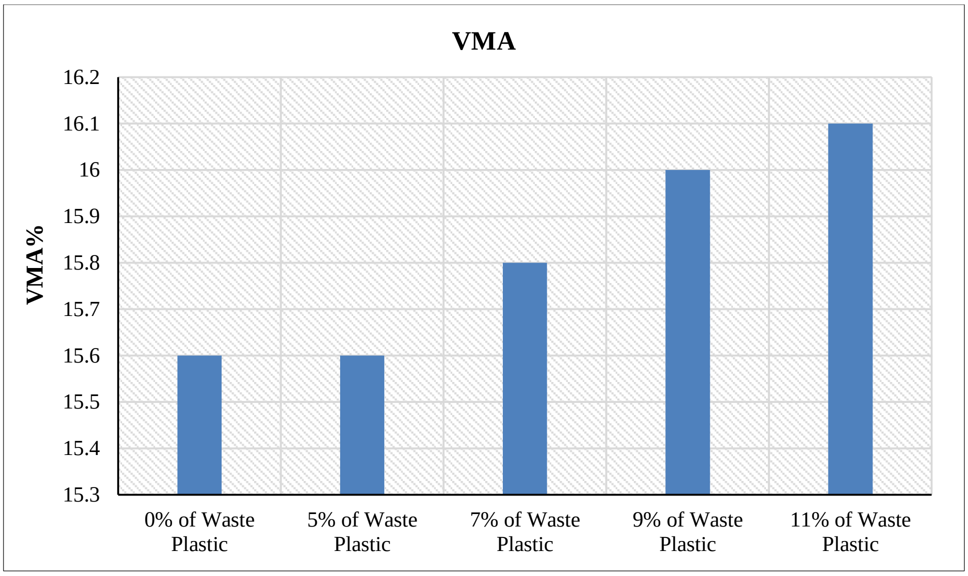

Figure 6. VMA versus percentage of added plastic particles

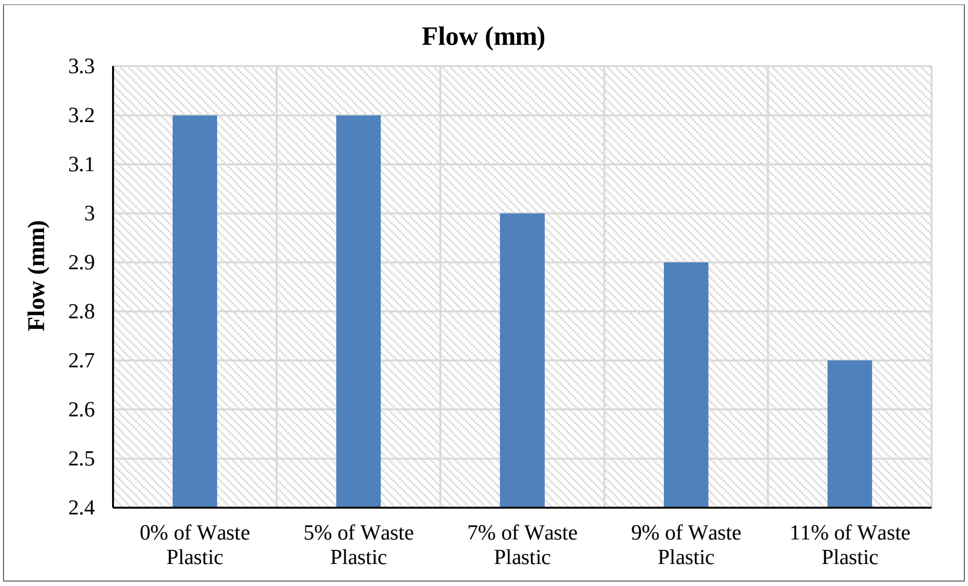

Figure 7. Flow versus percentage of added plastic particles

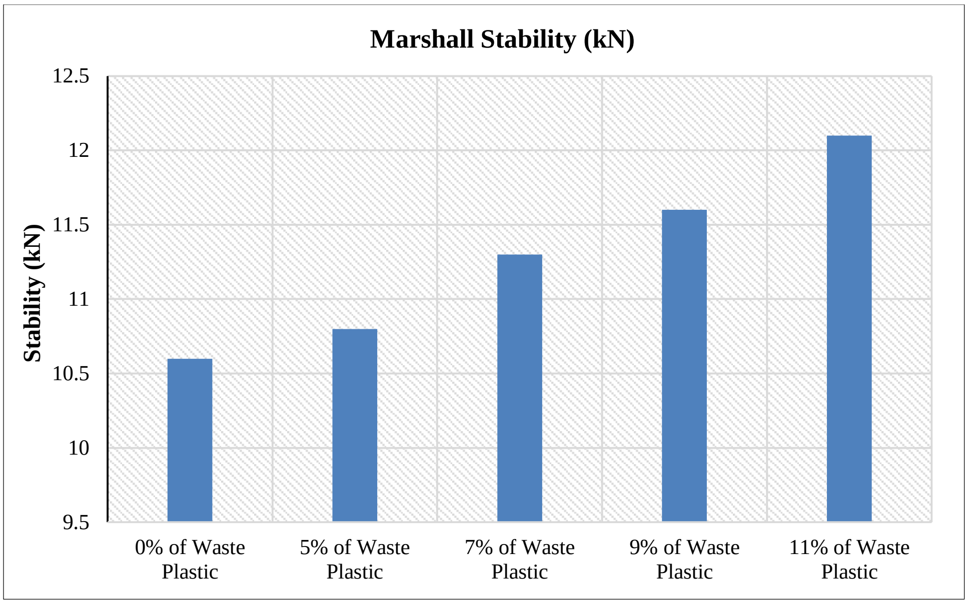

Figure 8. Marshall stability versus percentage of added plastic particles

In Figure 9, the optimal asphalt content (OAC) for each mixture containing a certain percent of plastic particles was computed by taking the average values of asphalt contents at maximum unit weight, maximum stability, and asphalt median air void ratio. In the mixture containing 11% plastic, the asphalt content decreased by 13.5% compared to the standard mixture (i.e., 0% plastic), resulting in an economic benefit from the reduced use of asphalt. The asphalt content decreased as the percentage of plastic in the mixture increased because the plastic coated the aggregates and consequently reduced the air gaps. Similar results were found by Fonseca et al. [1].

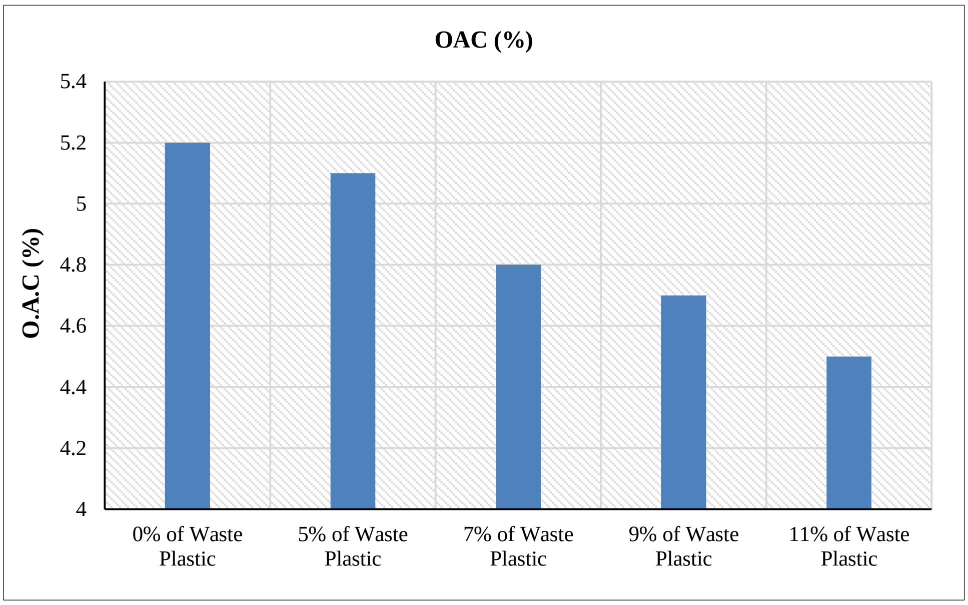

Figure 9. OAC versus percentage of added plastic particles

3.2. Resilient Modulus (RM)

After determining the optimal asphalt content for the samples, three samples were prepared for each plastic addition percentage. Table 7 and Figure 10 present the results of 1200 repetitions of indirect tensile load at 0.138 MPa and 25 °C on the RM of the samples. Increasing the percentage of plastic added to the sample results in an improvement in mixture elasticity and, consequently, a rise in resilient modulus values. Using 9 and 11% of plastic particles increased the percentage of the resilient modulus by more than 17 and 16%, respectively, compared to the controlled sample. The addition of plastic to the asphalt mixtures reduces its viscosity and thus increases the value of the resilient modulus. This is a good indicator for the use of recycled plastic in areas with hot climates to increase the asphalt's flexibility and, thus, its resistance to hot climates. Similar results were drawn by Abu Abdo & Khater [14].

Table 7. Results of Resilient Modulus

Percentages of adding plastic particles in asphalt concrete mixture	Resilient Modulus, MPa						
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Average	Increase rate %
0% plastic particles	1847	1820	1789	1797	1830	1816.6	-
5% plastic particles	1952	1923	1878	1852	1989	1918.8	5.33
7% plastic particles	2100	2012	1998	2052	2111	2054.6	13
9% plastic particles	2140	2088	2121	2078	2205	2126.4	17
11% plastic particles	2147	2014	2111	2201	2091	2112.8	16

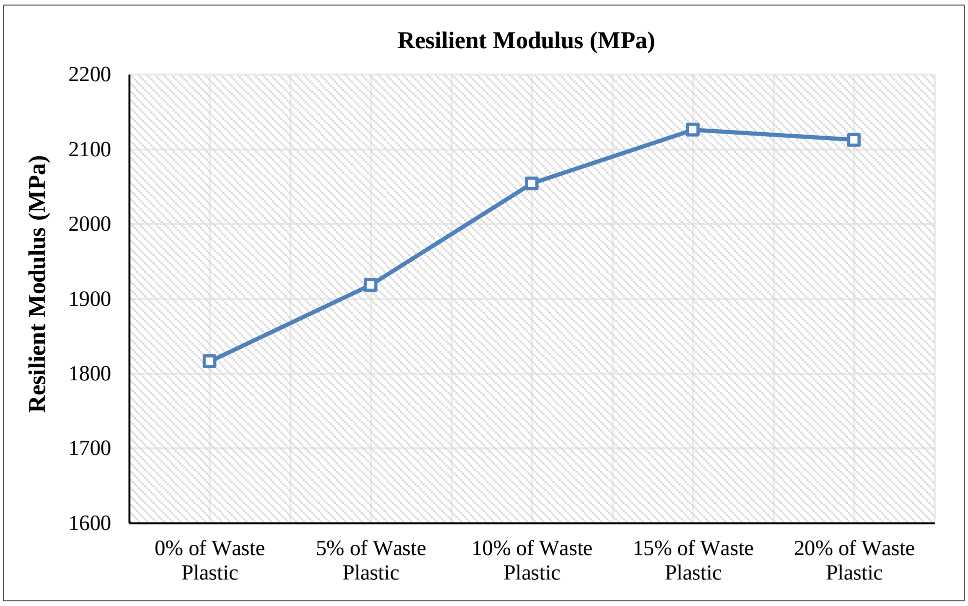

Figure 10. Resilient modulus versus plastic contents

4. Conclusion

Positive results are returning from using particles of plastic bottles in asphalt mixtures, which will lead to more research in this area. Most studies indicated that adding plastic to asphalt and concrete mixtures using the dry or wet method improves their properties. Chemically, the strength of bonds between aggregates increased as the plastic content increased, thereby increasing the cohesion of mixtures and their service life. An increase in Marshall's stability was observed in the mixtures with a certain percent of plastic. The optimal asphalt content used in the mixture decreased by 14% when adding 11% recycled plastic instead of fine aggregates. This indicates a positive reduction in the use of asphalt and reduces costs. Furthermore, a technique of reusing plastic in asphalt concrete mixtures is considered a significant method that declines the costs of recycling and disposal as well as reducing pollution effects on the climate and environment.

In conclusion, the addition of plastic particles to asphalt binders can be considered an environmental-friendly aspect of the plastic waste problem and an economical solution to enhance the modulus of elasticity and strength of asphalt without the need to use more expensive additives. In addition, replacing 9% of the fine aggregate with plastic particles showed an increase in the resilient modulus of 17%. That means an increase in the mixture's durability and flexibility and strengthening the bonds between the aggregates. This feature reduces asphalt deformation, aggregate separation from the mixture, and maintenance costs. Finally, questions regarding the semi-permanent performance impact of plastic in asphalt pavements, environmental impacts, health and safety effects, and re-recyclability of asphalt mixtures need to be investigated by other researchers in the future. Using other mix design methods, such as Superpave, and applying different polymers in cold mix asphalt are suggested for further research.

5. Declarations

5.1. Author Contributions

Conceptualization, H.A.; methodology, H.A., N.A., and S.M.; validation, H.A., N.A., and S.M.; investigation, H.A., N.A., and S.M.; resources, H.A.; writing—original draft preparation, H.A.; writing—review and editing, N.A., H.A., and S.M. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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